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Non-volant mammal inventory of western Mongolian-Manchurian Grassland Ecoregion: a biogeographic crossroad worth preserving

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Abstract

The extensive Mongolian grasslands hosts a high variety of micro-habitats which wildlife uses as corridors that enable species to expand their range. Between May 2017 and March 2018, we conducted an intensive survey in the Mongolian-Manchurian Grassland Ecoregion using camera trapping, field transects, live trapping and opportunistic observations, in mountain outcrops, grass steppe and sand dune habitats across seasons. Our aim was to compile the first satisfactory inventory of mammals based on scientific methods for a diverse landscape in the Mongolian provinces of Tov and Dundgovi. Furthermore, our research seeks to fill in knowledge gaps on species distribution and range expansions in the endangered west Mongolian-Manchurian Grassland ecoregion and identify biodiversity hotspot areas encompassed in this biogeographic crossroad. We recorded 31 species of non-volant mammals, including a globally Endangered species and two Near Threatened species, according to the IUCN Red List, and three species listed in Appendix II of CITES.

Keywords

Biodiversity, camera trapping, live trapping, mammal checklist, Mongolian steppe, range expansion, species distribution.

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Introduction

The Mongolian–Manchurian Grassland Ecoregion (MMGE) is characterized by extensive grasslands spreading from central Mongolia to northeastern China (west to east) and from southern Siberia to Inner Mongolia (north to south) (Hilbig 1995; MacKinnon 1996). The ecoregion has been categorized as Critically Endangered by the World Wildlife Fund (Carpenter 2019). Steppe adapted ungulates, such as the *Procapra gutturosa* (Pallas, 1777), carnivores like *Canis lupus chanco* (Gray, 1863), and high diversity of rodents, characterize the mammalian fauna of the MMGE (Batsaikhan et al. 2014; Lebedev et al. 2016). *Procapra przewalskii* (Büchner 1891) has been extirpated from the MMGE (Batsaikhan et al. 2014) as a direct result of human activity, which has increased in the last decades as China and Mongolia became the main exporters of cashmere wool in the world (Lecraw et al. 2005). The change from a

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centralized market to an open market after the socialist system collapsed in 1990s (Dorj and Yavuuhulan 2003) enabled a constant growth of the cashmere market in Mongolia (Danforth 2017). This caused a huge increase in cashmere goats, from approximatively 20 million in 1990 to over 60 million in 2018 (NSOM 2019). The great number of small-sized livestock has been found to have a negative effect on wild ungulate occupancy (Rovero et al. 2018), as well as heightened competition for trophic resources with wild ungulates (Berger et al. 2013). Furthermore, hunting for wild game and retaliatory killings of carnivores are widespread in this region (Wingard and Zahler 2006). Our research area in the MMGE can be deemed as a biogeographic crossroad (Spector 2002), as it adjoins the Daurian Forest Steppe ecoregion from the north, the Selenge Orkhon Forest Steppe ecoregion from the west, and the Eastern Gobi Desert Steppe ecoregion from the south. This makes the area particularly important to study in order to fill in the knowledge gaps on mammalian species distribution in the western MMGE, which is currently little studied. Lack of information on species distribution is a critical issue for conservation planning known as the Wallacean shortfall (Bini et al. 2006; Hortal et al. 2015). Data on species occurrences in the area are currently based on reporting from local people (mainly sightings and hunting) and perception (i.e. identifying carcasses killed by carnivores), and has not been supported by scientific documentation (such as photos or genetic analysis), which otherwise could have reduced species misidentifications. A single scientific study has been conducted in the study area which had focused on two ungulates species (Lkhagvasuren et al. 2016) as a part of a nation-wide survey for *Ovis darwini* (Przewalkski, 1883). Current study seeks to fill in knowledge gaps on the non-volant mammalian species distribution within the western MMGE with adjoining ecoregions using a suite of methods, including camera trapping, field transects, live trapping, and opportunistic sightings. Furthermore, we investigate range expansions for some species, historically absent or never previously recorded in the area.

Methods

Study area. The data collection was conducted in Western MMGE (Fig. 1), from May 2017 to March 2018, covering a total area estimated to be ~10,000 km^2. Our sampling area falls within the Mongolian provinces of Tov (47.4209°N, 106.5647°E, datum WGS84) and Dundgovi

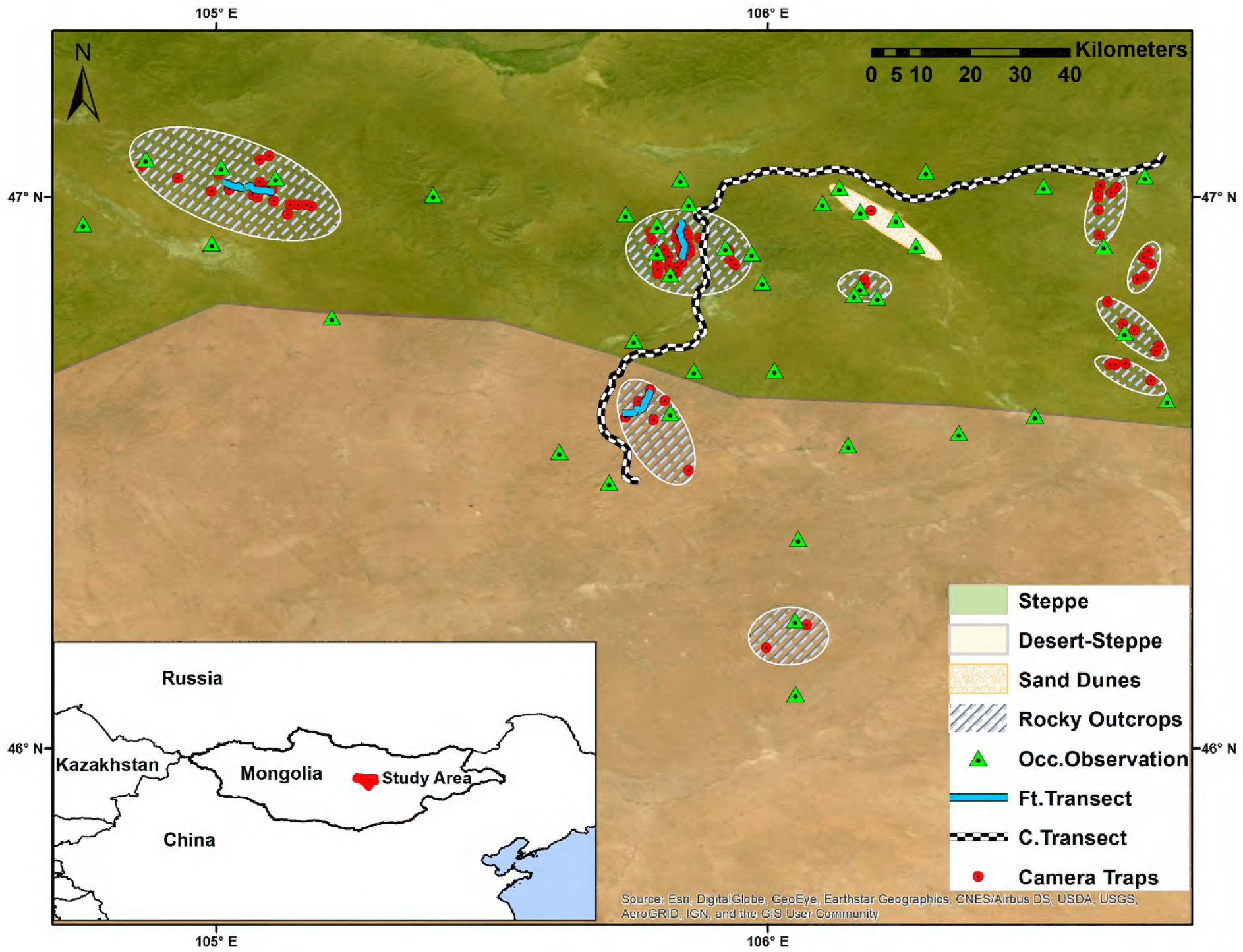

Figure 1. Map of study area in the Mongolian-Manchurian Grassland Ecoregion within the two provinces of Tov and Dundgovi, Mongolia. The five polygons inside the total sampling area represent the zones sampled by camera traps, live traps and transects on foot. A. the blue triangles "Opp. Obs." represents opportunistic observations, "Ft. transect" represent the transects made by foot and "C. transect" represent the transects made by car. Red triangles represent all camera traps locations in this study.

(45.4611°N, 106.1707°E, datum WGS84, elevations ranging between 965 and 1809 m a.s.l.). This region is warm in summer (average 16 °C in August) and cold in winter (average −23 °C in January) (UNEP 2011). The precipitation ranges between ~270 mm in July to <50 mm in January (UNEP 2011). Largest plant families occurring in the area are Asteraceae, Poaceae, Fabaceae, and Chenopodiaceae, characterizing the steppe ecosystem in the northern zone and the desert-steppe in the southern zone of the research area. There are no restrictions on livestock number and the area is used for pastures with evidence of overgrazing (Shimada et al. 2009). The globally Endangered *Marmota sibirica* (Radde, 1862) (IUCN 2019), and the Near Threatened *Ovis darwini* (Przewalski, 1883) and *Otocolobus manul* (Pallas, 1776) (IUCN 2019) are thought to occur in this area (Batsaikhan et al. 2014; Lkhagvasuren et al. 2016). Among the large carnivores *Canis lupus chanco* (Gray, 1863) and *Lynx lynx isabellinus* (Blyth 1847) have been reported to occur in the region by local herders. The study area is scarcely populated, holding a population of approximately 5000 inhabitants (NSOM 2019), including five villages and Mongolian gers belonging to nomadic pastoralists spread across the area. We used a suite of survey methods in an attempt to maximize detection likelihood of both elusive but large-bodied mammals through camera trapping, live trapping of small mammals, along with planned transects and opportunistic sightings.

Within the survey period, we covered an area of approximately 2360 km^2, calculated using the minimum convex polygon method (Worton 1987). We favoured a simple model for estimating the size of the surveyed area based on all records, indiscriminate of species or type of data point. Thus, the need for a more recently developed model, which are intended to calculate precise home-ranges based on animal movement we deemed redundant. The five zones were located across five districts (Mongolian soum): Bayan Onjuul (46°52.80′N, 105°53.40′E, datum WGS84, area surveyed: 1091 km^2), Buren (47°00.96′N, 105°03.00′E, datum WGS84, area surveyed: 451 km^2), Bayantsagaan (46°45.60′N, 107° 08.40′E, datum WGS84, area surveyed: 238 km^2), Adatsaag (46°36.60′N, 105°17.40′E, datum WGS84, area surveyed: 440 km^2), and Delgertsogt (46°12.00′N, 106° 14.40′E, datum WGS84, area surveyed: 140 km^2).

Camera trapping. In each of the five zones (Fig. 1) we placed between six and 25 cameras (UOVision 565HD IR+ and Reconyx HC600) per sampling period, repeated four times: May to July 2017, July to October 2017, October to December 2017, December 2017 to March 2018. Between these periods, the cameras were moved to adjacent areas within each zone and the batteries and SD cards were replaced. We deployed a single camera trap at a height of 30–50 cm above the ground ~4–5 m from the target trail (Tobler et al. 2008). Distance between sites were 1–3 km within each zone. The habitats covered included rocky outcrops and an area with sand dunes. The cameras were aimed at marking points, forced passages, trails on ridges, and valley bottoms.

Live trapping. The live-trapping surveys were conducted in May, July and August 2017, across the Bayan Onjuul zone, using Sherman (PLFA, 7.62 × 8.89 × 22.86 cm) and pitfall traps (diameter 20 cm). The habitats targeted for live trapping were grass steppe, sand dunes, and rocky outcrops. Traps were set at 10 m intervals, with 20 traps per site (10 Sherman and 10 pitfall) in May and July, and 40 traps per site (30 Sherman and 10 pitfall) in August. The traps were baited with peanut butter, honey, and oats. Live trapped animals were sexed and weighed using a Pesola spring balance (precision: 0.05g). Using digital metal callipers (0.01mm accuracy), morphometric measurements recorded were lengths of head-body, tail, head, fibula, metatarsus, and radio-ulna. Traps were checked twice daily, early morning and late afternoons. All animals were found alive and immediately released at the place of capture after being measured, weighed and photographed.

Transects. Eighty, 1 km transects were established on foot around the rocky outcrops, overlapping with camera trap locations, in Bayan Onjuul, Buren, and Adatsaag (Fig. 1). Transects were conducted in May and July 2017. We recorded all locations where mammals were sighted and took photos when possible, according to a standardized technique (Buckland et al. 2001). During the same period, thirty transects, each 10 km long, were conducted by car keeping a constant speed of 30 km/h. The car transects covered steppe and dry-steppe habitat between Bayantsagaan and Adatsaag (Fig. 1). Recordings were conducted according to the protocol previously described for transects on foot.

Opportunistic sighting. We recorded all species observed occasionally during transportation by car in the study area, or on foot during day and night (Fig. 1). All species and locations of mammals observed alive or dead were recorded.

Data analyses. Species recorded from camera trap footage were entered using the open-access software Wild. ID (Bolger et al. 2012). Images were filtered for independent detection events (i.e., time between two captures of the same species, at the same location, was set to minimum 30 minutes) to avoid multiple entries of the same individuals. Camera trap data were analyzed using the statistical program R (R Development Core Team, 2018), where an Index of Relative Abundance (RAI) and naïve occupancy (MacKenzie et al. 2002; O'Brien 2011) was estimated for each species using the R package "vegan" (Oksanen et al. 2019). Finally, to assess our sampling effort and get an indication of whether we had managed to capture all species in our study area, a species accumulation curve (Gotelli and Colwell 2001), was produced using the R package "vegan" (Oksanen et al. 2019), using the exact function to find the expected mean species richness (Rovero and Zimmermann 2016). Species

identifications were based on morphological characters using identification keys (Batsaikhan et al. 2014; Smith et al. 2010). Scientific names and conservation statuses were annotated for recorded species according to the IUCN Red List (IUCN 2019), Red List of mammals of Mongolia (Clark et al. 2006), and CITES Appendices (see Table 1).

Results

A total 31 species of mammals belonging to 12 families and five orders were recorded (Table 1). The family with the highest representation was the Cricetidae (eight species), followed by Sciuridae, Muridae, Canidae, Mustelidae, and Bovidae (three species per family). Two species from the Dipodidae family were recorded, as was one species from Felidae, Cervidae, Erinaceidae, Leporidae, and Otochonidae (Table 1). The highest number of species were recorded via opportunistic observations (n = 18) (Table 1). Fifteen species were detected using live traps, 12 species were detected by camera traps, and nine species were detected by transects (Table 1).

Cervus canadensis (Linneaus, 1758) showed the highest RAI value (4.65) and was the most frequently detected species with 174 independent events from camera traps (Table 2). *Ovis darwini* showed a high detection rate (83) and a high RAI (2.22), despite independent events being roughly half of those observed for *C. canadensis*. These two species were detected in approximately 70% of camera trap locations, having the highest naïve occupancy values (Table 2).

The species accumulation curve for expected species richness (Fig. 2) found that the majority of the species (n = 7) were recorded by camera traps in the first quarter of our survey (approximately at 600 trap-nights). The species accumulation curve did not level out completely into an asymptote (Fig. 2), despite an effort of 3741 nights-traps.

Live trapping contributed uniquely in detecting small mammals. Species from the families Lagomorpha and Rodentia were detected in steppe, dry steppe, mountainous areas, sand dunes, and close to human settlements. *Meriones meridianus* (Pallas, 1773) and *Meriones unguiculatus* (Milne-Edwards, 1867), were

Table 1. Species list of non-volant mammals detected in the western Mongolian-Manchurian Grassland Ecoregion and their global conservation status. The conservation status referring to the IUCN Red List (2019) and CITES Appendices. IUCN Red List code: LC = Least Concern, NT = Near Threatened, EN = Endangered. CITES code: App. II = species listed under CITES Appendix II, NL = not listed. For "recording methods": O = opportunistic observation; C = camera trap record; L = live trapped; T = transect. Area designates habitat of occurrence: TSA = throughout the study area.

Order	Family	Scientific name	Vernacular name	IUCN	CITES	Detection method	Area
Carnivora	Canidae	*Canis lupus* (Linnaeus, 1758)	Grey wolf	LC	App. II	C	Steppe; Desert-steppe
	Canidae	*Vulpes corsac* (Linnaeus, 1768)	Corsac fox	LC	NL	O/C/T	TSA
	Canidae	*Vulpes vulpes* (Linnaeus, 1758)	Red fox	LC	NL	O/C/T	TSA
	Felidae	*Otocolobus manul* (Pallas, 1776)	Pallas cat	NT	App. II	C	Steppe
	Mustelidae	*Martes foina* (Erxleben, 1777)	Beech marten	LC	NL	C	Steppe; Desert-steppe
	Mustelidae	*Meles leucurus* (Hodgson, 1847)	Asian badger	LC	NL	C	Steppe
	Mustelidae	*Mustela eversmanii* (Lesson, 1827)	Steppe polecat	LC	NL	O	Steppe
Cetartiodactyla	Bovidae	*Capra sibirica* (Pallas, 1776)	Siberian ibex	LC	NL	O/C	Steppe; Desert-steppe
	Bovidae	*Ovis darwini* (Przewalski, 1883)	Gobi argali	NT	App. II	O/C/T	Steppe; Desert-steppe
	Bovidae	*Procapra gutturosa* (Pallas, 1777)	Mongolian gazelle	LC	NL	O/T	TSA
	Cervidae	*Cervus canadensis* (Erxleben, 1777)	Wapiti	LC	NL	O/C/T	Steppe; Desert-steppe
Eulipotyphla	Erinaceidae	*Hemiechinus dauuricus* (Sundevall, 1842)	Daurian hedgehog	LC	NL	O	Steppe
Rodentia	Cricetidae	*Allocricetulus curtatus* (Allen, 1925)	Mongolian hamster	LC	NL	L	Steppe
	Cricetidae	*Alticola semicanus* (Allen, 1924)	Mongolian silver vole	LC	NL	L/C	Steppe
	Cricetidae	*Cricetulus barabensis* (Pallas, 1773)	Striped dwarf hamster	LC	NL	L	Steppe; Desert-steppe
	Cricetidae	*Cricetulus longicaudatus* (Edwards, 1867)	Long-tailed dwarf hamster	LC	NL	L	Steppe
	Cricetidae	*Lasiopodomys brandtii* (Radde, 1861)	Brandt's vole	LC	NL	O/L/T	TSA
	Cricetidae	*Microtus limnophilus* (Büchner, 1889)	Lacustrine vole	LC	NL	L	Steppe
	Cricetidae	*Phodopus campbelli* (Thomas, 1905)	Campbell's dwarf hamster	LC	NL	L/O	Steppe; Desert-steppe
	Cricetidae	*Phodupus roborovskii* (Satunin, 1903)	Roborovski's hamster	LC	NL	L	Steppe
	Dipodidae	*Allactaga sibirica* (Forster, 1778)	Mongolian five-toed jerboa	LC	NL	O/L	Steppe
	Dipodidae	*Dipus sagitta* (Pallas, 1773)	Hairy-footed jerboa	LC	NL	L	Steppe
	Muridae	*Apodemus peninsulae* (Thomas, 1906)	Korean field mouse	LC	NL	L	Steppe
	Muridae	*Meriones meridianus* (Pallas, 1773)	Midday gerbil	LC	NL	O/L	Steppe
	Muridae	*Meriones unguiculatus* (Milne-Edwards, 1867)	Mongolian gerbil	LC	NL	O/L/T	TSA
	Muridae	*Mus musculus* (Linnaeus, 1758)	House mouse	LC	NL	L	Steppe
	Sciuridae	*Marmota sibirica* (Radde, 1862)	Siberian marmot	EN	NL	O	Steppe; Desert-steppe
	Sciuridae	*Spermophilus pallidicauda* (Satunin, 1903)	Pallid ground squirrel	LC	NL	O	Steppe
	Sciuridae	*Urocitellus undulates* (Pallas, 1778)	Long-tailed ground squirrel	LC	NL	O	Steppe; Steppe; Steppe
Lagomorpha	Leporidae	*Lepus tolai* (Pallas, 1778)	Tolai hare	LC	NL	O/C/T	TSA
	Ochotonidae	*Ochotona dauurica* (Pallas, 1776)	Daurian pika	LC	NL	O/C/T/L	TSA

the most frequently captured mammal species, while all other species were captured once or twice each (Table 3). *Urocitellus undulatus* (Pallas, 1778) was the most recorded rodent species by transect. The number of large-bodied ungulates, i.e. *Ovis darwini* and *Cervus canadensis*, were also recorded often during transects (Table 4). The most frequently detected species by opportunistic observation was the *Procapra gutturosa*, due to their large herds occurring across the steppe, they were easy to spot from a distance of approximately 1 km (Table 5). A roadkill of a *Hemiechinus dauuricus* (Sundevall, 1842) was found and recorded in the steppe near our camp, as was the case for a *Mustela eversmanii* (Lesson, 1827). No other detections were obtained for these two species, but local herders claim that they are relatively common in the area.

Table 2. Descriptors of species' presence: RAI = Relative abundance index; Naïve Occupancy = Proportion of sites where the species was detected; Independent events = Independent detection events (captures with a minimum time of 30 minutes between two captures of the same species at the same location).

Scientific name	Vernacular name	RAI	Naïve occupancy	Independent events
Cervus canadensis	Wapiti	4.65	0.70	174
Ovis darwini	Gobi argali	2.22	0.74	83
Vulpes vulpes	Red fox	1.84	0.52	69
Ochotona dauurica	Daurian pika	1.82	0.13	68
Lepus tolai	Tolai hare	0.99	0.30	37
Martes foina	Beech marten	0.59	0.35	22
Capra sibirica	Siberian ibex	0.16	0.22	6
Canis lupus	Grey wolf	0.08	0.09	3
Otocolobus manul	Pallas cat	0.05	0.09	2
Vulpes corsac	Corsac fox	0.03	0.04	1
Meles leucurus	Asian badger	0.03	0.04	1

Table 3. List of species recorded by live trapping. Quantity = number of specimens captured per species. Percentage of total captures = number of captures per species / total captures of all the species * 100. Trap type = type of traps used for capture.

Scientific name	Vernacular name	Quantity	% of total captures	Trap type
Phodopus roborovskii	Roborovski's hamster	1	1.5	Pitfall
Phodopus campbelli	Campbell's dwarf hamster	1	1.5	Sherman
Dipus sagitta	Hairy-footed jerboa	1	1.5	Sherman
Allocricetulus curtatus	Mongolian hamster	2	2.9	Pitfall
Cricetulus longicaudatus	Long-tailed dwarf hamster	1	1.5	Sherman
Ochotona dauurica	Daurian pika	1	1.5	Sherman
Meriones meridianus	Midday jerbil	19	27.9	Sherman
Microtus limnophilus	Lacustrine vole	1	1.5	Sherman
Meriones unguiculatus	Mongolian gerbil	38	55.9	Sherman
Apodemus peninsulae	Korean field mouse	1	1.5	Sherman
Cricetulus barabensis	Striped dwarf hamster	1	1.5	Sherman
Alticola semicanus	Mongolian silver vole	1	1.5	Sherman

Annotated list of records

Carnivora (Canidae)

***Canis lupus* (Linnaeus, 1758)**

Figure 3A

New record. MONGOLIA • Province of Dundgovi; 46° 38.02′N, 105°45.92′E; 24 May 2017; camera trap photo.

Identification. The largest wild Canidae of Mongolia has a short tail and grey fur (yellowish in summer) (Batsaikhan et al. 2014). It cannot be misidentified with other canids occurring in the study area.

Table 4. List of species detected by transects. Count = number of individuals per species recorded by transects. Car count = number of individuals per species recorded by car transects. Total sighting = total number of individuals per species recorded by car and foot transects.

Scientific name	Vernacular name	Count	Car count	Total sighting
Ovis darwini	Gobi argali	12	2	14
Cervus canadiensis	Wapiti	15	0	15
Vulpes vulpes	Red fox	1	3	4
Lepus tolai	Tolai hare	6	1	7
Ochotona dauurica	Daurian pika	7	0	7
Cricetulus barabensis	Striped dwarf hamster	1	0	1
Allactaga sibirica	Mongolian five-toed jerboa	0	1	1
Meriones unguiculatus	Mongolian gerbil	8	0	8
Spermophylus undulatus	Long-tailed ground squirrel	5	16	21

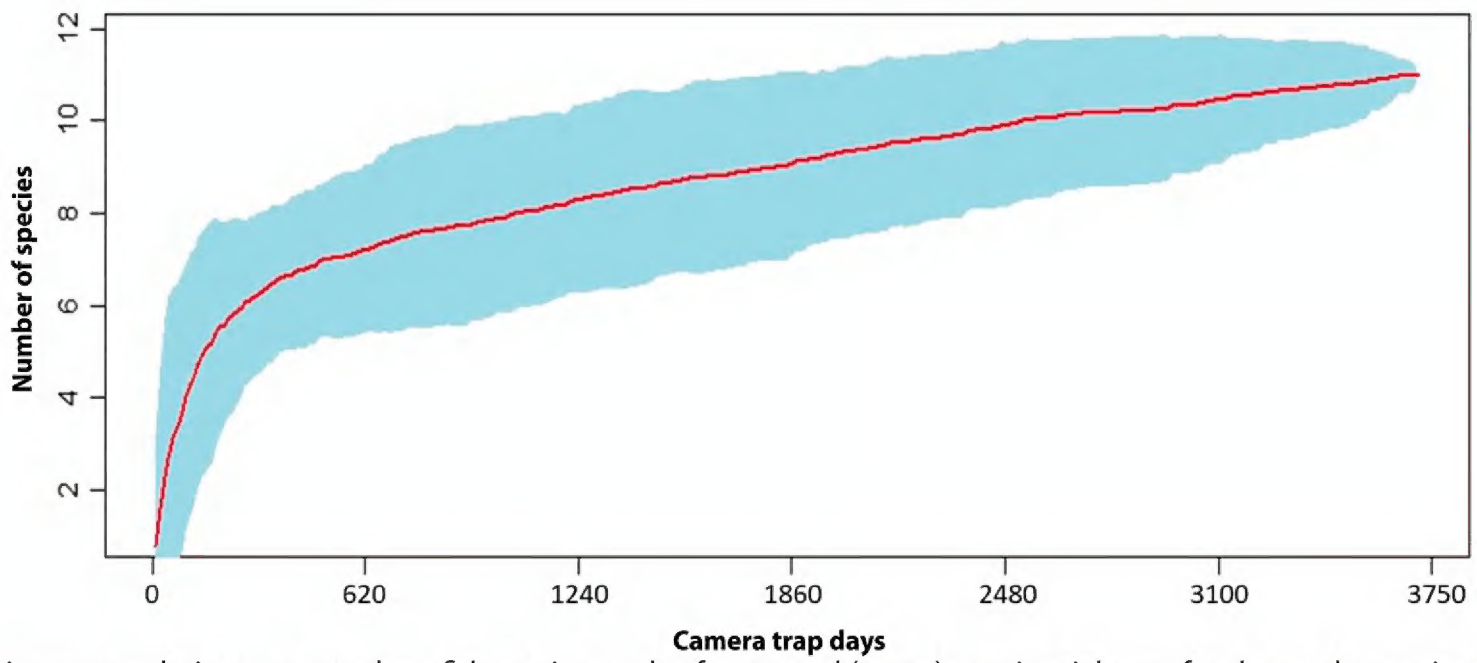

Figure 2. Species accumulation curve and confidence intervals of expected (mean) species richness for the study area in the Mongolian-Manchurian Grassland Ecoregion within the two provinces of Tov and Dundgovi, Mongolia. Number of camera trapping days is shown on the x-axis, while number of species detected is shown on the y-axis. Note that despite the high effort (3741 camera trap nights) the curve does not level out, indicating that additional species are likely to occur in the study area.

Table 5. List of species detected by opportunistic observations. Live = live detected individuals. Dead = individuals detected as carcasses. Total sighting = the total number of individuals detected by opportunistic observations including live and dead individuals.

Scientific name	Vernacular name	Live	Dead	Total sighting
Procapra gutturosa	Mongolian Gazelle	508	11	519
Capra sibirica	Siberian Ibex	4	0	4
Ovis darwini	Gobi Argali	7	1	8
Cervus canadiensis	Wapiti	19	1	20
Vulpes vulpes	Red Fox	2	1	3
Vulpes corsac	Corsac Fox	1	0	1
Mustela eversmanii	Steppe Polecat	0	1	1
Lepus tolai	Tolai Hare	4	0	4
Ochotona dauurica	Daurian Pika	6	0	6
Lasiopodomys brandtii	Brand's Vole	8	0	8
Cricetulus barabensis	Striped Dwarf Hamster	2	0	2
Allactaga sibirica	Five-toed Jerboa	1	1	2
Meriones unguiculatus	Mongolian Gerbil	27	0	27
Mus musculus	House Mouse	1	0	1
Marmota sibirica	Siberian Marmot	1	0	0
Spermophylus undulatus	Long-tailed Ground Squirrel	8	1	9
Spermophylus pallicaudata	Pallid Ground Squirrel	1	0	1
Mesechinus dauuricus	Daurian Hedgehog	0	1	1

Carnivora (Canidae)
***Vulpes corsac* (Linnaeus, 1768)**
Figure 3B

New record. MONGOLIA • Province of Tov; 47°4.78′N, 106°1.97′E; 15 May 2017; opportunistic observation.

Identification. Smaller than *Vulpes vulpes* (Linnaeus, 1758), identified by its black tail tip (*V. vulpes* has a white tail tip), and light yellow forelegs (Sillero-Zubiri 2009).

Carnivora (Canidae)
***Vulpes vulpes* (Linnaeus, 1758)**
Figure 3C

New record. MONGOLIA • Province of Tov; 46°59.36′N, 106°21.73′E; 10 May 2017; opportunistic observation.

Identification. Distinguished from *Vulpes corsac* by its longer tail, larger body-size (head-body length: 35–50 cm, tail length: 30–55 cm, weight 2.2–14 kg for *V. Vulpes*; head-body length: 45–65 cm, tail: 19–35 cm, weight 1.6–3.2 kg for *V. corsac*), white tail tip, and the reddish color that covers all its dorsal fur (Batsaikhan et al. 2014).

Carnivora (Felidae)
***Otocolobus manul* (Pallas, 1776)**
Figure 3D

New record. MONGOLIA • Province of Tov; 46°56.05′N, 105°27.43′E; 2 Aug. 2017; camera trap photo.

Identification. The only small cat occurring in the study area. Easily recognizable by its bushy tail and long, dense fur (Batsaikhan et al. 2014).

Carnivora (Mustelidae)
***Martes foina* (Erxleben, 1777)**
Figure 3E

New record. MONGOLIA • Province of Tov; 46°31.71′N, 105°33.82′E; 23 Jul. 2017; camera trap photo.

Identification. The only species of the genus *Martes* present in the study area. Long slender body, fur dark grey-brown, typically with a white bib (Batsaikhan et al. 2014).

Carnivora (Mustelidae)
***Meles leucurus* (Hodgson, 1847)**
Figure 3F

New record. MONGOLIA • Province of Tov; 46°33.24′N, 105°29.85′E; 27 Jul. 2017; camera trap photo.

Identification. Easily identified by its black and white facial mask. The only badger in the study area (Larivière and Jennings 2009). It cannot be mistaken for any other species.

Carnivora (Mustelidae)
***Mustela eversmanii* (Lesson, 1827)**
Figure 3G

New record. MONGOLIA • Province of Tov; 46°58.55′N, 105°55.39′E; 16 Mar. 2018; opportunistic observation (carcass/roadkill).

Identification. A characteristic light-colored head with a black mask around the eyes. Body light, yellowish and beige, occasionally white-gray. Underside uniformly dark-red and black fur (Batsaikhan et al. 2014).

Bovidae (Caprinae)
***Capra sibirica* (Pallas, 1776)**
Figure 3H

New record. MONGOLIA • Province of Tov; 46°12.55′N, 105°58.95′E; 16 May 2017; opportunistic observation.

Identification. Siberian Ibex is the only wild goat species in Mongolia, and there is no similar species. Both male and female have long backwards curved horns and a long beard (Batsaikhan et al. 2014).

Bovidae (Caprinae)
***Ovis darwini* (Przewalski, 1883)**
Figure 4A

New record. MONGOLIA • Province of Dundgovi; 46° 56.37′N, 105°50.63′E; 12 May 2017; opportunistic observation.

Identification. The largest wild sheep (genus *Ovis*) in the world; with its concentric horns it cannot be misidentified with any other Bovidae occurring in central Mongolia (Groves and Leslie 2011).

Bovidae (Antilopinae)
***Procapra gutturosa* (Pallas, 1777)**
Figure 4B

New record. MONGOLIA • Province of Tov; 46°43.74′N, 105°44.49′E; 14 May 2017; opportunistic observation.

Identification. Mongolian Gazelle has lateral and facial markings like the non-*Procapra* gazelle species, but

Figure 3. Photographs of mammal species photographed during our sampling by camera traps or during the fieldwork. **A.** *Canis lupus* **B.** *Vulpes corsac*. **C.** *Vulpes vulpes*. **D.** *Otocolobus manul*. **E.** *Martes foina*. **F.** *Meles leucurus*. **G.** *Mustela eversmanii*. **H.** *Capra sibirica*.

Figure 4. Photographs of mammal species photographed during our sampling by camera traps or during the fieldwork. **A.** *Ovis darwini*. **B.** *Procapra gutturosa*. **C.** *Cervus canadensis*. **D.** *Hemiechinus dauuricus*. **E.** *Allocricetulus curtatus*. **F.** *Alticola semicanus*. **G.** *Cricetulus barabensis*. **H.** *Cricetulus longicaudatus*.

less pronounced; the naked tail is covered by long pale-brown hair at the top and a stout body with slender legs, these are particular characteristics that identify the species from *Gazella subgutturosa* (Güldenstädt, 1780) (Groves and Leslie 2011).

Bovidae (Cervinae)
***Cervus canadensis* (Severtov, 1853)**
Figure 4C

New record. MONGOLIA • Province of Tov; 46°56.05′N, 105°50.08′E; 12 May 2017; opportunistic observation.

Identification. The biggest ungulate of central Mongolia and the only Cervidae occurring in the study area. Easily recognized by its large antlers and white-cream rump patch (Batsaikhan et al. 2014). The subspecies *sibiricus* lives from Tien Shan to the Altai mountain, from north Xinjiang to south Siberia and north Mongolia (Mattioli 2011).

Eulipotyphla (Erinaceidae)
***Hemiechinus dauuricus* (Sundevall, 1842)**
Figure 4D

New record. MONGOLIA • Province of Tov; 46°58.56′N, 105°55.39′E; 16 Jul. 2017; opportunistic observation (carcass/roadkill).

Identification. It is the only species of hedgehog present in the study area. Identified by spines covering the entire upper body (Batsaikhan et al. 2014).

Rodentia (Cricetidae)
***Allocricetulus curtatus* (Allen, 1925)**
Figure 4E

New record. MONGOLIA • 1 ♀, 117mm; Province of Tov; 46°57.66′N, 106°12.07′E; 16 Jul. 2017; caught in live trap.

Identification. Identified by morphological characteristics. Fur on head and upper body buff, throat and underside lighter. Short tail and rat-like head (Lissovsky 2016).

Rodentia (Cricetidae)
***Alticola semicanus* (Allen, 1924)**
Figure 4F

New record. MONGOLIA • 1 ♂, 90mm; Province of Tov; 46°57.11′N, 105°50.01′E; 15 Jul. 2017; caught in live trap.

Identification. Identified by morphological characteristics. Silver-gray dorsal fur with light to white underside, characteristic long hair, and white tail (Lissovsky 2016).

Rodentia (Cricetidae)
***Cricetulus barabensis* (Radde, 1861)**
Figure 4G

New record. MONGOLIA • Province of Dundgovi; 46°58.51′N, 105°55.32′E; 6 Aug. 2017; opportunistic observation.

Identification. Identified by morphological characteristics. Dorsal fur grey to brown with dark dorsal stripe. Differs from *Phodopus campbelli* by shorter snout, longer tail and less distinct color difference between dorsal and ventral fur (Lissovsky 2016).

Rodentia (Cricetidae)
***Cricetulus longicaudatus* (Milne-Edwards, 1867)**
Figure 4H

New record. MONGOLIA • 1 ♂, 128 mm; Province of Tov; 46°57.11′N, 105°50.00′E; 15 Jul. 2017; caught in live trap.

Identification. Identified by morphological characteristics. Ventral fur white-grey and dorsal pelage grey to light brown without dorsal stripe. Long tail compared to other hamsters occurring in the area (Pardiñas et al. 2017).

Rodentia (Cricetidae)
***Lasiopodomys brandtii* (Radde, 1861)**
Figure 5A

New record. MONGOLIA • Province of Dundgovi; 46°57.66′N, 106°12.07′E; 7 Aug. 2017; opportunistic observation.

Identification. Identified by morphological characteristics. Fur on head and upper body sandy gray, underside white-gray. Tail fur uniformly yellowish. Sole of foot has six plantar pads, approximately three are covered by hair (Lissovsky 2016).

Rodentia (Cricetidae)
***Microtus limnophilus* (Büchner, 1889)**
Figure 5B

New record. MONGOLIA • 1 ♂, 98mm; Province of Dundgovi; 46°58.07′N, 106°12.44′E; 15 May 2017; caught in live trap.

Identification. Identified by morphological characteristics. Various color morphs are reported. Upper body often gray-brown with a rusty back. Short ears, blunt head, and small eyes. Six plantar pads on hint foot (Lissovsky 2016).

Rodentia (Cricetidae)
***Phodopus campbelli* (Thomas, 1905)**
Figure 5C

New record. MONGOLIA • 1 ♂, 76 mm; Province of Tov; 46°58.51′N, 105°55.32′E; 13 May 2017; caught in live trap.

Identification. Identified by morphological characteristics. Dorsal fur gray to wood-brown, underside white. Has a narrow black dorsal stripe, starting on the head going to the base of the tail. Tail and legs are cream and lighter than the body (Pardiñas et al. 2017).

Rodentia (Cricetidae)
***Phodopus roborovskii* (Satunin, 1903)**
Figure 5D

New record. MONGOLIA • 1 ♀, 40 mm; Province of Tov; 47°1.83′N, 105°57.36′E; 19 Jul. 2017; caught in live trap.

Figure 5. Photographs of mammal species photographed during our sampling by camera traps or during the fieldwork. **A.** *Lasiopodomys brandtii*. **B.** *Microtus limnophilus*. **C.** *Phodopus campbelli*. **D.** *Phodopus roborovskii*. **E.** *Allactaga sibirica*. **F.** *Dipus sagitta*. **G.** *Apodemus peninsulae*. **H.** *Meriones meridianus*.

Identification. Identified by morphological characteristics. Dorsal fur light brown to yellow; underside white. No black stripe on back, *P. roborovskii* is smaller than *Phodopus campbelli* (Thomas, 1905) (Pardiñas et al. 2017).

Rodentia (Dipodidae)
***Allactaga sibirica* (Forster, 1778)**
Figure 5E

New record. MONGOLIA • 1 ♂, 322 mm; Province of Tov; 46°58.51′N, 105°55.32′E; 17 Jul. 2017; caught in live trap.

Identification. Identified by morphological characteristics. Very long legs and characteristic well-furred white tail tip with a distinctive black mid band, head and dorsal side lightly grey, white flanks and underside. Easily recognized by its long broad ears, and five toes on hind foot (Michaux and Shenbrot 2017).

Rodentia (Dipodidae)
***Dipus sagitta* (Pallas, 1773)**
Figure 5F

New record. MONGOLIA • 1 ♂, 239 mm; Province of Dundgovi; 46°57.67′N, 106°12.90′E; 8 Aug. 2017; caught in live trap.

Identification. Identified by morphological characteristics. *Dipus sagitta* and *Allactaga sibirica* (Forster,1778) are the only jerboa species in the study area. The species has a longer tail and shorter ears compared with the *A. sibirica* (Batsaikhan et al. 2014). *Dipus sagitta* only has three toes on hind foot.

Rodentia (Muridae)
***Apodemus peninsulae* (Thomas, 1906)**
Figure 5G

New record. MONGOLIA • Province of Tov; 47°2.13′N, 105°57.56′E; 14 May 2017; opportunistic observation.

Identification. Identified by morphological characteristics. The only *Apodemus* species in the study area. A medium-sized rodent with brown-red pelage, darker back, and long tail. Presence of small granules between the plantar pads on feet is a distinguishing character of the species (Pardiñas et al. 2017).

Rodentia (Muridae)
***Meriones meridianus* (Pallas, 1773)**
Figure 5H

New record. MONGOLIA • 1 ♀, 127 mm; Province of Tov; 46°57.66′N, 106°12.06′E; 15 Jul. 2017; caught in live trap.

Identification. Identified by morphological characteristics. Tail is longer than the head and body. Differs from *Meriones unguiculatus* in having a less-developed tuft of the tail that are occasionally absent. The dorsal part of the tail is yellowish brown and its ventral part is light yellow. Underbelly is white. Soles on hind feet are covered with hairs. Claws are white with a reddish upper part (Darvish 2009; Smith et al. 2010).

Rodentia (Muridae)
***Meriones unguiculatus* (Milne-Edwards, 1867)**
Figure 6A

New record. MONGOLIA • 1 ♂, 130 mm; Province of Dundgovi; 46°58.51′N, 105°55.32′E; 16 Jul. 2017; caught in live trap.

Identification. Identified by morphological characteristics. Sandy-colored fur, long and hairy tail, especially on the edge where it becomes dark. Claws are black (Batsaikhan et al. 2014).

Rodentia (Muridae)
***Mus musculus* (Radde, 1861)**
Figure 6B

New record. MONGOLIA • Province of Tov; 46°58.71′N, 105°55.79′E; 7 Aug. 2017; opportunistic observation.

Identification. Identified by morphological characteristics. Sandy gray fur, underside lighter. Occasionally dark grey with a darker tail. Large round ears (Lissovsky 2016).

Rodentia (Scuridae)
***Marmota sibirica* (Radde, 1862)**
Figure 6C

New record. MONGOLIA • Province of Dundgovi; 46° 50.61′N, 105°59.31′E; 17 Jul. 2017; opportunistic observation.

Identification. It is the only marmot species occurring in the study area. Long stocky body with short legs, fur color varying from black to grey on upper body, underside usually yellow to red (Schai-Braun and Hackländer 2016).

Rodentia (Sciuridae)
***Spermophilus pallidicauda* (Satunin, 1903)**

New record. MONGOLIA • Province of Tov; 46°54.55′N, 105°42.39′E; 7 Aug.2017; opportunistic observation.

Identification. Characteristic stocky body and short tail (tail <55 mm; Smith et al. 2010). It has reddish spots beneath the eyes with a yellow chin and hairless hind feet (Batsaikhan et al. 2014; Smith et al. 2010).

Rodentia (Scuridae)
***Urocitellus undulatus* (Pallas, 1778)**
Figure 6D

New record. MONGOLIA • Province of Tov; 46°55.08′N, 105°51.99′E; 15 May 2017; opportunistic observation.

Identification. Identified by morphological characteristics. It can be distinguished from *Spermophilus pallidicauda* by its considerably longer and larger tail (tail length: 3.5–5.3 cm for *S. pallidicauda*; tail length: 10–14 cm for *U. undulatus*) (Batsaikhan et al. 2014; Smith et al. 2010).

Largomorpha (Leporidae)
***Lepus tolai* (Pallas, 1778)**
Figure 6E

Figure 6. Photographs of mammal species photographed during our sampling by camera traps or during the fieldwork. **A.** *Meriones unguiculatus*. **B.** *Mus musculus*. **C.** *Marmota sibirica*. **D.** *Urocitellus undulates*. **E.** *Lepus tolai*. **F.** *Ochotona dauurica*.

New record. MONGOLIA • Province of Tov; 43°15.19′N, 106°7.03′E; 12 May 2017; opportunistic observation.

Identification. During the summer the fur color of *L. tolai* is lighter than *Lepus timidus* (Linnaeus,1758), the only other Leporidae occurring in Mongolia. Tail color is typically all white with black tips and a golden edge (Batsaikhan et al. 2014). The only species of Leporidae recorded from the study area.

Largomorpha (Ochotonidae)
***Ochotona dauurica* (Pallas, 1776)**
Figure 6F

New record. MONGOLIA • Province of Tov; 46°55.08′N, 105°51.99′E; 13 May 2017; opportunistic observation.

Identification. Two species of pikas occur, *Ochotona pallasii* (Gray, 1867) and *O. dauurica* in the Province of Tov, the largest part of our study area. The dorsal fur in *O.dauurica* is brown and in *O. pallasi* ocherous gray, ventral side is white in *O. dauurica* and sandy in *O. pallasi* (Lissovsky 2016).

Discussion

In this study we have addressed the Wallacean shortfall (Hortal et al. 2015) on species occupancy and distribution of mammals in the MMGE. We found the areas that likely serve as a refugia for some locally and globally threatened species (Clark et al. 2006; IUCN 2019). We found that this relatively small area holds a high diversity and represents an important intersection for mammalian distributional ranges between Mongolian ecoregions. All of the 31 species recorded in this study were detected in the Bayan Onjuul district (Table 1) in a minimum convex polygon of approximately 50 km^2 between the sand dunes and the mountainous area transecting the steppe.

This hotspot area covers <1‰ of Mongolia's total land area (1.5 million km^2) and holds >25% of all non-volant mammal species, 31 of 122 non-volant mammals living in Mongolia (Lebedev et al. 2016).

In our study, we observed for the first time new distribution records for three species namely, *Cervus canadensis*, *Phodopus roborowski*, and *Microtus limnophilus*. *Cervus canadensis* appears to have undergone a recent range expansion to the south, *P. roborowski* has expanded approximately 200 km north, and *M. limnophilus* has expanded 200 km east compared to the findings of Batsaikhan et al. (2014). *Cervus canadensis* is normally associated with forest-steppe habitat; however, it was found to be abundant around rocky outcrops during our study. This species was also recorded in Adatsaag in desert-steppe habitat where shrubs are very scarce. This is approximately 200 km south of the previously known distribution range of *C. canadensis* (Batsaikhan et al. 2014; IUCN 2019). *Cervus canadensis* had a naïve occupancy of 0.7 throughout our study area and the highest RAI of any species at 4.65. This was a surprise finding, given that the expansion of *C. canadensis* apparently has happened within the last 15 years according to local herders (Claudio Augugliaro pers. comm.). However, in a previous countrywide survey for *Ovis darwini* by Lkhagvarsuren et al. (2016), *C. canadensis* was not reported to be present in our study area. It is a surprising discovery that *C. canadensis* has apparently undergone a range expansion as the species has declined by more than 90% in Mongolia over the last decades (Zahler et al. 2004). This is especially interesting, as our study area had high presence of humans and livestock, which has previously been found to negatively affect *C. canadensis* populations (Thapaliya 2008). When exactly the expansion has happened remains unknown, but individual *C. canadensis* would have had to cross a minimum of 50 km of open steppe to reach the rocky outcrops where we detected them in.

Our results confirm that the western MMGE holds important refugia for a viable *O. darwini* population. The species is even more widespread across our study area with the highest naïve occupancy of any species (0.74), higher than previously assessed (Lkhagvasuren et al. 2016). While the RAI for *O. darwini* was lower than *C. canadensis* at 2.22, our findings are still encouraging, as the species is considered Near Threatened and declining (Groves and Leslie 2011). Interestingly, *O. darwini* co-occurs with *C. canadensis* in our study area, and further studies are necessary to investigate the relationship between these two ungulates. *Capra sibirica* was recorded across rocky outcrops throughout the study area, though in lower abundance than the other ungulate species occurring here.

The low-lying areas represent an important grazing site for the *Procapra gutturosa*, which occurs in the study area throughout the year. Between mid-September and mid-October, we observed several large herds in the flat grasslands, hilly steppe, and sand dunes that included thousands of individuals. In the sand dunes, multiple carcasses were discovered in early autumn and assumed to have been killed and eaten by wolves, which were captured by camera traps in the sand dunes.

Although we recorded seven species of carnivores, their abundance appeared to be low (three detections of *Canis lupus*, two of *Otocolobus manul*, one of *Meles leucurus*, one carcass of *Mustela eversmanii*). The two fox species and the beech marten were detected more frequently throughout our study area. Despite the high abundance of prey and apparent suitable habitat, human presence likely has a negative effect on the presence of carnivores with regular hunting/retaliatory killings and a high number of dogs. Camera trapping appears to be the only reliable method for confirming the presence of elusive carnivores in the Mongolian context (Augugliaro et al. 2019), where the hunting is common and the wildlife protection is rarely effective. However, a specific sampling design should be addressed to each carnivore species in order to detect the highest number of photographic detections.

The species accumulation curve derived from the findings of camera trapping showed our checklist is probably incomplete, and we suspect that additional species may occur in the area (i.e., *Lynx lynx* reported by locals, as well as other mustelid species). A higher number of camera traps in a multiple-years sampling regime would likely yield a result with better confidence on mammalian species richness (Si et al. 2014). We also recommend an in-depth analysis concerning the co-occurrence of the ungulate species and developing a mammal monitoring program for the area that we identify as a habitat and biodiversity hotspot of Mongolian.

Additional live trapping surveys in a broader survey area and an increase in sampling effort would likely to increase species detection of small mammals.

In this study we have found that an unprotected area of just 50 km^2 can harbour more than 25% of the non-volant mammal species recorded in Mongolia. Our study emphasises how a heterogeneous landscape can act as important refugia for multiple species and potential stepping-stone for range expansions. Heterogeneous landscapes may be more important than previously assumed and should be considered as important areas for wildlife conservation.

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Authors' Contributions

CA, CJ, and BL conceived the research framework. CA, CJ, IEM, RWH, and LWH collected the data in the field. CA analyzed the data. CA and RWH wrote the manuscript. RWH produced the figures. CA, LWH, RWH, and BL revised the manuscript. All authors discussed the results and contributed to the final manuscript.

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